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# Effects of increasing levels of oat hulls or sugar beet pulp in the diet on growth performance, gastrointestinal tract development, and nutrient retention in broilers from one to eighteen days of age[1]

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## ABSTRACT

The effects of increased levels of oat hulls (OH) and sugar beet pulp (SBP) in the diet on growth performance, digestive traits, and nutrient retention were studied in broilers from 1 to 18 d of age. A control diet based on rice that contained 1.6% crude fiber (6.9% dietary fiber) was diluted with 2.5, 5.0, and 7.5% of either OH or SBP and each of the 7 treatments was replicated 6 times (a cage with 12 chicks). Growth performance, digestive organ development, and total tract apparent retention (TTAR) of nutrients were recorded at 6, 12, and 18 d of age and jejunal morphology at 12 and 18 d of age. Fiber source inclusion did not affect ADG but feed-to-gain ratio estimated by regression was best with 3.7% of inclusion. An increase in fiber increased linearly the weight ($P \leq 0.001$) and the DM content ($P \leq 0.05$) of the gizzard and decreased linearly ($P \leq 0.01$) gizzard pH. Broilers fed OH had heavier gizzards with more DM content and higher digesta pH ($P \leq 0.001$) than broilers fed SBP. The inclusion of SBP in the diet reduced villus height ($P \leq 0.01$) and crypt depth ($P \leq 0.05$) as compared with the inclusion of OH. The TTAR of all nutrients studied increased ($P \leq 0.001$) with the inclusion of 2.5% of a fiber source but not with 7.5% inclusion. We conclude that the inclusion of moderate amounts of a source of fiber (up to 5%) into a low fiber diet improves nutrient digestibility and feed efficiency but that a further increase to 7.5% hinders broiler productivity. The requirement for crude fiber of young chicks varies between 2.0 to 2.9% of the diet (8.2 to 10.1% dietary fiber), depending on the variable considered and the source of fiber used. Lower levels of inclusion of dietary oat hulls than of sugar beet pulp are required to maximize nutrient retention in young broilers.

**Keywords:** crude fiber, fiber source, broiler performance, digestive traits, nutrient retention

## INTRODUCTION

Dietary fiber (**DF**) has been considered as a diluent and an antinutritional factor in poultry diets because of its negative effects on energy intake and nutrient digestibility (Sklan et al., 2003; Rougière and Carré, 2010). Consequently, commercial diets for young broilers are formulated to contain less than 3% crude fiber (**CF**). However, recent studies indicate that the inclusion of moderate amounts of fiber in the feed improves HCl, bile acids, and enzyme production (Hetland et al., 2003) as well as nutrient digestibility and growth performance in broilers fed low-fiber diets (Jiménez-Moreno et al., 2009a; González-Alvarado et al., 2010). The values of CF values do not represent the real fiber content of the diets (Mertens et al., 2003). These authors recommends the utilization of DF, a term that comprises the soluble and insoluble non-starch polysaccharides and lignin of plant cell walls as well as the resistant starch. The beneficial effects of including a source of fiber in the diet on growth performance are probably related to improvements in gizzard development (González-Alvarado et al., 2008). A well-developed gizzard increases intestinal refluxes facilitating the mixing of the digesta with HCl and enzymes, which in turn may improve the solubility of the mineral fraction of the diet and the digestibility of CP and other dietary components (Guinotte et al., 1995; Svihus and Hetland, 2001; Jiménez-Moreno et al., 2009b). In contrast, an excess of fiber may hinder ADFI, nutrient digestibility, and growth performance (Jørgensen et al., 1996a; Sklan et al., 2003, Jiménez-Moreno et al., 2011). Thus, the magnitude of the response to DF may depend on the level and type of fiber used.

The physicochemical properties of fibrous ingredients such as solubility, water holding capacity (**WHC**), viscosity, bulk, fermentability, and ability to bind bile acids have nutritional implications on ADFI, gastrointestinal tract (**GIT**) development, and nutrient digestibility in non-ruminants (Montagne et al., 2003). The soluble fractions of DF such as pectins from sugar beet pulp (**SBP**) are dispersible in water, and might increase viscosity and bulk of the digesta (Bach

Knudsen, 2001) resulting in delayed gastric emptying and increased intestinal transit time. In addition, this soluble fraction may entrap physically bile acids and phospholipids (Story and Kritchersky, 1982) interfering with the mixing of the digesta and the diffusion of nutrients through the absorptive surface of the gut (Forman and Schneeman, 1980). On the other hand, the lignified insoluble fraction of DF, such as that present in oat hulls (**OH**), stimulates gizzard activity, increases intestinal passage rate, and favours peristaltic movements which may result in improved nutrient digestibility (Hetland and Svihus, 2001; Hetland et al., 2003; Jiménez-Moreno et al., 2010). Therefore, type and level of DF may affect in different ways nutrient utilization and broiler growth. The hypothesis of this research was that the inclusion of moderate amounts of fiber into low fiber diets may improve nutrient digestibility and growth performance in broilers but that an excess may have opposite effects. The aim of this study was to evaluate the effect of increasing levels of two fiber sources (OH or SBP) with different physicochemical properties on growth performance, development of the GIT, mucosa morphology, and nutrient retention of broilers from 1 to 18 d of age.

## MATERIAL AND METHODS

***Fiber Sources and Diets***

A batch of OH and a batch of SBP were obtained from Biessa (Burgos, Spain) and Azucarera Olmedo (Valladolid, Spain), respectively. The two fiber sources were ground using a hammer mill (Model 15303, Fritsch GmbH, Rudolstadt, Germany) fitted with a 2-mm screen. The basal diet was based on rice, soy protein concentrate, and fish meal (Table 2) and contained 3,250 kcal $AME_n$/kg and 1.6% CF (6.9% DF). Acid-washed diatomaceous earth (Celite Hispánica S.A., Alicante, Spain) was added at 2% to the basal diet as an additional source of acid-insoluble ash. The remaining experimental diets were manufactured by diluting (wt/wt) the control diet with 2.5, 5.0, or 7.5% of either OH or SBP. All diets were fed in mash form and met or exceeded the nutritional recommendations of Fundación Española Desarrollo Nutrición Animal (2008) for broilers.

***Broiler Husbandry and Experimental Design***

All procedures used in this research were approved by the Animal Ethics Committee of the Universidad Politécnica de Madrid and were in compliance with the Spanish guidelines for the care and use of animals in research (Boletín Oficial del Estado, 2007).

A total of 504 one-d-old Ross 308 female chicks with an initial BW of 42.0 ± 3.3 g was obtained from a commercial hatchery (Avimosa, Moraleja de Enmedio, Spain), allocated in an environmentally controlled room, and randomly placed in groups of 12 in 42 battery cages (1 m x 0.9 m; Avícola Grau, Madrid, Spain) equipped with 2 drinker cups and an open trough feeder. Chicks were divided into 6 blocks by weight and the diets were randomly assigned to cages within each block. Room temperature was kept at 33º C during the first 3 d of life and then it was reduced gradually according to age until reaching 24º C at 18 d. Chicks received a 23 h/d light program and had free access to feed and water throughout the trial. The trial was conducted as a completely randomized block design with 7 dietary treatments consisting in a negative control diet without any extra source of fiber and 6 additional diets arranged factorially with 2 sources of dietary fiber (OH and SBP) and 3 levels of fiber inclusion (2.5, 5.0, and 7.5%).

***Analytical Evaluation of Ingredients, Feeds, Excreta, and Ileal contents***

Fiber sources, diets, excreta, and ileal digesta were analyzed for moisture by oven-drying (method 930.15), total ash by muffle furnace (method 942.05), and nitrogen (**N**) by Dumas (method 968.06) using a LECO analyzer (model FP-528, Leco Corporation, St. Joseph, MI) as described by AOAC International (2000). Gross energy was measured with an isoperibol bomb calorimeter (model 356, Parr Instrument Company, Moline, IL) and acid- insoluble ash was analyzed as indicated by de Coca-Sinova et al. (2011). Ether extract (**EE**) of the fiber sources, diets, and excreta was analyzed by Soxhlet fat analysis after 3*N* HCl acid hydrolysis (method 4.b) as described by Boletín Oficial del Estado (1995). Starch content of the fiber sources and diets was measured using amyloglucosidase/α-amylase (method 996.11) and CF by sequential extraction with diluted acid and alkali (method 962.09 as indicated by AOAC International, 2000). Total DF (method 985.29) and the insoluble fraction of DF (method 991.43) of the fiber sources and diets were analyzed by an enzymatic-gravimetric method (AOAC International, 2000) using the Total Dietary Fiber Kit (Megazyme International Ireland Ltd., Wicklow, Ireland). Soluble DF content was calculated by difference between total and insoluble DF. Neutral detergent fiber (**NDF**), acid detergent fiber (**ADF**) and acid detergent lignin (**ADL**) of fiber sources and diets were determined sequentially as described by Mertens (2002) for NDF and AOAC International (2000) (method 973.187) for ADF and ADL, respectively and expressed on an ash-free basis. The NDF and ADF were determined using a filter bag system (Ankom Technology, Macedon, NY). Particle size distribution and geometric mean diameter (**GMD**) of fiber sources and diets were determined according to the methodology of the ASAE (1995). Swelling capacity, WHC, and capacity to adsorb lipids of the fiber sources were determined as reported by Jiménez-Moreno et al. (2011). All analyses were conducted in triplicate except for ileal samples that were analyzed in duplicate.

***Growth Performance and Water Intake***

Body weight of chicks and feed consumption were determined by cage at 1, 6, 12, and 18 d of age. Feed wastage and birds that died during the experiment were recorded daily. The ADG, ADFI, and feed-to-gain ratio (**F:G**) were determined from these data by period and cumulatively. In addition, energy efficiency expressed as kcal of $AME_n$ required per g of ADG, was estimated for each of the three experimental periods (6, 12, and 18 d of age) and cumulatively as indicated by Jiménez-Moreno et al. (2011). Finally, water intake was measured from 6 to 8 d and from 16 to 18 d of age, and the water:feed intake ratio was estimated from these data.

***Digestive Traits and Jejunal Morphology***

At 6, 12, and 18 d of age two chicks per cage were randomly selected, weighed individually, and euthanized by asphyxiation with $CO_2$. The digestive tracts with contents (from the end of the crop to the cloaca) were removed aseptically and weighed. Then, the liver, pancreas, proventriculus, gizzard, small intestine (duodenum + jejunum + ileum), and ceca were excised, cleaned, dried with desiccant paper, and weighed. Prior to digesta emptying, the proventriculus, gizzard, and duodenum (from the gizzard to the entry of the bile and pancreatic ducts) were clamped to avoid bolus contamination among segments and the digesta pH was then measured in each of the segments as indicated by Jiménez-Moreno et al. (2009c). Also, the relative weight of the digestive organs and the relative weight of the fresh digesta content of the proventriculus, gizzard, and ceca (g/kg BW) were measured as indicated by Jiménez-Moreno et al. (2011). Dry matter of the gizzard contents were determined by oven-drying at 60º C for 72 h and the values expressed relative to BW (g DM/kg BW). The length of the small intestine and ceca were recorded and expressed relative to empty BW (cm/kg) at same ages. Villi height and associated crypts depth of samples taken from the middle part of the jejunum were measured in one of the birds slaughtered per cage at 12 and 18 d of age and the villi height:crypt depth ratios were determined as described by Jiménez-Moreno et al. (2011).

***Total Tract Apparent Retention of Nutrients and Apparent Ileal Digestibility***

At 6, 12, and 18 d of age, the DM content of the excreta was determined by replicate in representative samples (235 ± 25 g). Also, at these ages the excreta produced for the previous 48 h was collected daily, mixed, homogenized, dried in an oven (60º C for 72 h), and weighed again.

Then, the samples were ground with a rotor mill (Retsch GmbH Model ZM 200, Hann, Germany) fitted with a 1.0-mm screen. At 18 d of age, the ileal digesta contents of 5 birds per replicate chosen at random were collected by gently flushing the contents with distilled water into plastic containers, pooled, frozen at -20ºC, and freeze-dried. Dried ileal digesta samples were ground using a mixer mill (Retsch GmbH Model MM 400, Haan, Germany) and stored in airtight containers at room temperature until chemical analyses. The total tract apparent retention (**TTAR**) of DM, organic matter, N, soluble ash, and EE, and the $AME_n$ of the diets as well as the apparent ileal digestibility (**AID**) of DM, organic matter, and N, were estimated by the indigestible marker method using 2*N* HCl insoluble ash as an indicator. The TTAR and AID of nutrients and the $AME_n$ of the diets were calculated as described by Jiménez-Moreno et al. (2011) and Lázaro et al. (2003), respectively.

***Statistical Analysis***

Data on growth performance and water consumption were analyzed as a completely randomized block design with a 1 (control) + 2 × 3 factorial arrangement of treatments using the GLM procedure of SAS (SAS Institute, 1990). Preplanned orthogonal contrasts were performed to study the effects of fiber (control diet vs. supplemented fiber diets) and source of fiber (OH vs. SBP) on these traits. Polynomial contrasts were performed to study the linear and quadratic responses of the different traits to the level of fiber source inclusion (2.5, 5.0, and 7.5%) and age (6, 12, and 18 d of age). Also, the interaction between source and level of fiber was studied. For data on DM content of the excreta, development of the GIT, digestive traits, jejunal morphology, and TTAR of nutrients, age and the interaction between diet and age were included in the model. The experimental unit was the cage for all traits and differences were considered significant at $P < 0.05$. In addition, a non-orthogonal contrast was made to compare the mean of the control and the diets that contained 7.5% of a fiber source. To reduce type I error, Bonferroni's test was used for this comparison. Data on DM content of the excreta and TTAR of nutrients were analyzed as repeated measures using the MIXED procedure of SAS (Littell et al., 1996) and those on digestive traits, jejunal morphology, DM content of the gizzard, and AID of nutrients were analyzed by the GLM procedure of SAS (SAS Institute, 1990). In addition, the optimal level of fiber inclusion in the diet for maximal performance was calculated by regression using the REG procedure of SAS (SAS Institute, 1990).

## RESULTS

Oat hulls and SBP contained 3.0 and 8.9% CP, 9.2 and 1.0% starch, 28.3 and 17.8% CF, 70.2 and 34.2% NDF, and 71.3 and 59.0% total DF, respectively (Table 1). The GMD, WHC, swelling water capacity, and capacity to adsorb lipids were 509 and 796 $\mu$m, 3.9 and 10.6 L/kg DM, 2.1 and 6.2 mL/g DM, and 2.1 and 1.3 g oil/g DM for OH and SBP, respectively. An increase in the level of inclusion of a fiber source resulted in a reduction in CP and $AME_n$, and an increase in NDF, ADF, and total DF content of the diet (Table 3). The soluble fraction of DF was reduced as dietary OH increased. The inclusion of a fiber source increased the GMD of the diet.

### *Growth Performance, Water Intake, and DM Content of the Excreta*

Mortality was low (3.4%) and not related to treatment (data not shown). Most of the mortality (> 80%) occurred during the first wk of life. An increase in the level of the fiber sources from 2.5 to 7.5% reduced linearly ADG from 1 to 6 d ($P \leq 0.01$) and from 6 to 12 d ($P = 0.06$) (Table 4). Consequently, from 1 to 18 d of age ADG tended to decline ($P = 0.09$) with increases in fiber inclusion. The inclusion of a fiber source in the diet tended to reduce ADFI of broilers for the first 12 d of age ($P \leq 0.1$; data not shown) but the effect disappeared thereafter. Source of fiber did not affect ADG in any of the periods studied. From 1 to 18 d of age an increase in the level of fiber from 2.5 to 7.5% impaired F:G linearly ($P \leq 0.01$) but improved ($P \leq 0.05$) energy efficiency (Table 5). Feed efficiency was similar for the diets that included 7.5% of a fiber source than for those observed with the control diet. When growth performance data were analyzed by regression including the data of the control diet, the best F:G was observed with 3.7% inclusion for both set of diets.

Source of fiber affected water intake and water:feed intake ratio in the two periods considered (Table 5). Broilers fed SBP had higher water intake from 6 to 8 d of age (72 vs. 67 g/d; $P \leq 0.01$) and from 16 to 18 d of age (122 vs. 113 g/d; $P \leq 0.05$) and higher water:feed intake ratio ($P \leq 0.001$) in the two periods than broilers fed OH. Consequently, the excreta was drier for birds fed OH than for birds fed SBP (41.7 vs. 33.6% DM; $P \leq 0.001$). The inclusion of 7.5% of a fiber source reduced ($P \leq 0.05$) DM content of the excreta as compared to the control diet. An interaction between source and level of fiber was observed on water:feed intake ratio in both periods ($P \leq 0.01$ from 6 to 8; and $P \leq 0.05$ from 16 to 18 d of age); an increase in dietary OH reduced linearly this ratio whereas an opposite effect was observed with SBP. Consequently, the DM content of the excreta was increased ($P = 0.07$) as dietary OH increased but no effect was observed with SBP.

***Organ Size, Digestive Traits, and Jejunal Morphology***

The relative weights of the pancreas (linear, $P \leq 0.001$), liver, and the segments of the GIT (linear, $P \leq 0.001$; quadratic, $P \leq 0.001$) decreased with age (Tables 6 and 7). The relative weights of the fresh content of the digesta of proventriculus (linear, $P \leq 0.001$) and gizzard (linear, $P \leq 0.001$; quadratic, $P \leq 0.01$) decreased with age (Table 8) whereas that of the ceca was higher (quadratic, $P \leq 0.001$) at 12 d than at 6 or 18 d of age. The relative length of the small intestine and ceca was reduced (linear and quadratic, $P \leq 0.001$) with age (Table 9). The pH of the digesta decreased ($P \leq 0.001$) with age (Table 10), an effect that was more evident in the upper part of the GIT (proventriculus and gizzard) than in the duodenum. The depth of the crypts of the jejunal epithelium was reduced ($P \leq 0.001$) with age but no effects were observed for villus height. Consequently, the villus height:crypt depth ratio increased ($P \leq 0.001$) with age (Table 11).

The relative weight of the full GIT (Table 6) and of the empty proventriculus and gizzard (Table 7) increased ($P \leq 0.001$) with increases in fiber inclusion. The relative length of the ceca also increased ($P \leq 0.01$) at 12 d of age with increases in fiber inclusion (Table 9). The inclusion of SBP increased the relative weight of the full GIT ($P \leq 0.001$) and pancreas ($P \leq 0.001$) as well as that of the empty proventriculus ($P \leq 0.001$) and ceca ($P \leq 0.01$) as compared with the inclusion of OH. The effects of increasing levels of fiber on gizzard weight tended to be more pronounced ($P = 0.08$) with OH than with SBP. Digesta content in the gizzard increased linearly ($P \leq 0.001$) with increases in fiber inclusion (Table 8). The effects of fiber inclusion on weight of the digesta content in the gizzard at 18 d of age were more evident ($P \leq 0.05$) with SBP than with OH. Dietary fiber increased linearly ($P \leq 0.05$) the weight of the dried digesta content of the gizzard that was higher ($P \leq 0.001$) with OH than with SBP (Table 8). Fiber inclusion reduced ($P \leq 0.001$) pH values in the upper part (proventriculus and gizzard) of the GIT with lower values ($P \leq 0.001$) observed with SBP than with OH. An increase in fiber inclusion from 2.5 to 7.5% reduced linearly the pH of the gizzard ($P \leq 0.01$) but increased that of the proventriculus ($P \leq 0.01$) and the duodenum ($P \leq 0.05$) (Table 10).

The villis were longer ($P \leq 0.01$) and the crypts deeper ($P \leq 0.05$) with OH than with SBP inclusion (Table 11). However, the villus height:crypt depth ratios were not affected by source of fiber. The inclusion of 7.5% of a fiber source reduced villus height (linear, $P = 0.06$; quadratic, $P \leq 0.05$) and tended to reduce villus height:crypt depth ratio ($P = 0.07$) as compared with the inclusion of 2.5 and 5.0%.

***TTAR and AID of Nutrients***

The TTAR of N (linear; $P \leq 0.001$; quadratic, $P \leq 0.01$), soluble ash and EE (linear; $P \leq 0.001$; quadratic, $P \leq 0.001$), and the $AME_n$ of the diet (quadratic, $P \leq 0.01$) were affected by age with the lowest values observed in general at 12 d of age (Table 12 and 13).

The inclusion of OH improved TTAR of N ($P \leq 0.001$), soluble ash ($P \leq 0.05$), and EE ($P \leq 0.001$), as well as the $AME_n$ of the diet ($P \leq 0.05$ at 6 and 12 d; $P \leq 0.001$ at 18 d of age) as compared with the inclusion of SBP. Also, TTAR of DM ($P \leq 0.05$) and OM ($P = 0.09$) at 18 d of age were higher with OH than with SBP. In general, the highest nutrient retention values were observed with the inclusion of 2.5% of a source of fiber and in fact, 7.5% inclusion reduced ($P \leq 0.001$) TTAR of all nutrients. Interactions between source and level of fiber were detected for TTAR of N ($P \leq 0.01$) and soluble ash ($P \leq 0.05$); lower retention values were observed with additional levels of fiber were more pronounced with SBP than with OH. Also, an interaction between source and level of fiber was detected for $AME_n$ of the diet at 6 d of age ($P \leq 0.05$); the reduction in $AME_n$ with increases in fiber inclusion at this age was more evident with SBP than with OH. The AID of DM and OM were higher ($P \leq 0.001$) with OH than with SBP inclusion and were reduced linearly ($P \leq 0.05$) as the level of fiber increased (Table 14). The AID of N tended to improve linearly ($P = 0.08$) with increased levels of OH but not with SBP.



## DISCUSSION

### *Growth Performance and Water Intake*

In general, the inclusion of 2.5% of a fiber source improved growth performance. The optimal fiber level for improved F:G estimated by regression analysis was 2.2 and 2.6% CF (8.9 and 9.3% total DF) for diets containing SBP and OH, respectively. Similarly, Pettersson and Razdan (1993) observed that broiler performance was improved when 2.3% SBP was included in the diet but that a further increase to 4.6 or 9.2% had negative effects. Also, Amerah et al. (2009) reported that the dilution of a basal diet with 6.0% wood shavings did not affect growth performance in broilers from 1 to 21 d of age. Hansen et al. (1992) in rats and Jørgensen et al. (1996b) in pigs reported that high fibrous diets increase the requirements of energy for maintenance which in turn may hinder F:G. In the current trial, an increase in fiber inclusion from 2.5 to 7.5% impaired ADG and F:G from 1 to 18 d of age but F:G was similar for birds fed the diet containing 7.5% fiber than for birds fed the control diet.

The inclusion of moderate amounts of fiber in the diet had little effect on ADFI. However, from 1 to 12 d of life, broilers fed 7.5% of a fiber source diet tended to eat less feed than broilers fed the control diet. In this respect, Rogel et al. (1987) reported that from 1 to 21 d of age broilers fed 2.0% OH had higher ADFI than broilers fed the control diet but no differences were observed with 4% or 6% OH. An increase in the level of fiber improved energy efficiency, an effect that was more pronounced with SBP than with OH. Probably, part of the fiber fraction of the SBP was fermented in the distal part of the GIT providing additional energy to the birds (Jørgensen et al., 1996a).

The water:feed intake ratio was higher and the DM content of the excreta lower for broilers fed SBP than for broilers fed OH, presumably because of the high pectin content of the SBP that increased water retention. The inclusion of SBP in the diet increased water intake without affecting feed consumption and consequently, the moisture content of the excreta was increased. Jørgensen et al. (1996a) observed an increase in moisture content of the excreta as the level of fiber from peas (high in pectin content) increased but not when oat bran was used.

***Digestive Traits and Jejunal Morphology***

In general, the relative weight of the liver and pancreas and of the different segments of the GIT, as well as the relative length of the small intestine and ceca, decreased with age results that agree with data of Ravindran et al. (2006) and González-Alvarado et al. (2008).

The relative weight of the full GIT and of the empty proventriculus and gizzard increased as the level of inclusion of fiber increased, in agreement with data of Jørgensen et al. (1996a) and Jiménez-Moreno et al. (2011). High fiber diets generate physical distension of the walls of the GIT increasing gut capacity and gutfill (Håkansson et al., 1978; Hetland and Svihus, 2001). The effects of fiber inclusion on the relative weight of the full GIT were more evident with SBP than with OH, an observation that is consistent with the higher pectin content of SBP.

An increase in fiber inclusion increased gizzard weight and its contents and reduced gizzard pH. The effects of additional fiber on gizzard weight were more evident with OH than with SBP. Oat hulls have higher concentration of insoluble fiber and lignin and are more resistant to grinding than SBP. In addition, OH particles are fusiform and consequently, maintain better its original physical structure after grinding than SBP (Jiménez-Moreno et al., 2010). Consequently, the amount of dried digesta retained in the gizzard was expected to be higher for OH than for SBP. The accumulation of fiber particles in the gizzard with feeding OH might induce a greater mechanical abrasion of the walls and stimulate further the development of the muscular layers of this organ than with feeding SBP (González-Alvarado et al., 2008; Jiménez-Moreno et al., 2010). On the other hand, SBP may be fermented partially in the ceca by the commensal microflora (Bach Knudsen, 2001). Consequently, the inclusion of SBP in the diet may cause an increase in the size of the ceca consistent with the observations of the current trial.

The villus height:crypt depth ratio is an useful criterion for estimating the digestive capacity of the small intestine (Montagne et al., 2003; Chou et al., 2009). In the current trial, the villus height:crypt depth ratio increased with age, in agreement with the observations of Murakami et al. (2007) and Chou et al. (2009). Also, crypt depth was lower at 18 d than at 12 d of age, in agreement with results of Batal and Parsons (2002) in broilers from 7 to 21 d of age, and consistent with the reduction in tissue turnover that occurs with age. The inclusion of 7.5% of a fiber source in the diet reduced villus height and villus height:crypt depth ratio and impaired nutrient retention. Probably, an excess of fiber increased the abrasion of the mucosal surface of the small intestine producing the shortening of the villis (Kelly et al., 1991; Yu and Chiou, 1997) and a decrease in nutrient digestibility.

Dietary SBP decreased villus height and crypt depth but the villus height: crypt depth ratio was not affected, in agreement with results of Hedemann et al. (2006) in pigs. A reduction in villus height has been observed also by Langhout (1998) in broilers fed a diet containing 3% of a highly-methylated citrus pectin and Iji et al. (2001) in broilers fed a commercial diet supplemented with 5% gum xanthan at 14 d of age.

***TTAR and AID of Nutrients***

The TTAR of most nutrients were lower at 12 d than at 6 or 18 d of age, an observation that is consistent with the lower villus height:crypt depth ratio observed. The inclusion of 2.5% of a fiber source in the diet improved TTAR of all nutrients whereas the inclusion of 7.5% had negative effects for all nutrients, except N and soluble ash of the OH diet. Rogel et al. (1987) reported increases in digestibility of raw potato starch in broilers as the level of OH in the diet increased from 0 to 12%. In contrast, Jørgensen et al. (1996a) observed a reduction in TTAR of nutrients and in AID of DM in 37 d-old broilers when 37.5% pea fiber or oat bran were included in the diet. In the current trial, the beneficial effects of additional fiber on AID of N and TTAR of nutrients were more evident with OH than with SBP. Sugar beet pulp is rich in pectins (Serena and Knudsen, 2007), a soluble fraction of DF that increases digesta viscosity and hinders the diffusion and absorption of nutrients in the distal part of the GIT (Forman and Schneeman, 1980; Johnson and Gee, 1981). The data indicate that the inclusion of moderate amounts of a fiber source (2.5%) benefits the development of the GIT and nutrient retention but that 7.5% affects negatively nutrient retention.

An increase in the level of fiber from 2.5 to 7.5% reduced TTAR of N consistent with data of Hallsworth and Coates (1962) and Green (1988) who indicated that diets high in CF enhanced abrasion of the mucosa in the small intestine of the birds, increasing endogenous cell losses to the lumen. The negative effects of fiber inclusion on N retention were more evident with SBP than with OH, an observation that is consistent with the findings of Leterme et al. (1996) who observed that the inclusion of pea hulls in the diet increased endogenous N losses in pigs. This observation is consistent with the increase in pancreas size observed with SBP inclusion in the current trial because pectins may have a secretagogic and trophic effect on the pancreas (Ikegami et al., 1990).

The inclusion of 7.5% of a fiber source in the diet reduced TTAR of soluble ash, an effect that was more evident with SBP than with OH. Pectins contained in SBP might enhance digesta viscosity preventing the absorption of metal ions and facilitating their elimination through the feces. In this respect, van der Aar et al. (1983) observed that chicks fed a diet rich in pectins had lower serum and tibia Mg concentration than chicks fed a diet rich in lignin. Also, Jiménez-Moreno et al. (2011) reported that the inclusion of 2.5 to 5% pea hulls in the diet but not of 7.5% improved soluble ash retention in young broilers.

Ether extract digestibility was highest in diets that contained 2.5% of a fiber source and better with OH than with SBP, consistent with data of González-Alvarado et al. (2007) who observed that fat digestibility was improved with OH supplementation. However, the inclusion of 7.5% SBP reduced EE digestibility to values below those of the control diet. Jiménez-Moreno et al. (2009a) observed that the beneficial effects of fiber inclusion on fat digestibility were more evident with saturated than with unsaturated fat, suggesting that bile salts production was higher in chicks fed additional fiber. In fact, Hetland et al. (2003) reported that the inclusion of 10% OH in the diet increased the concentration of bile acids in the chyme of broilers. On the other hand, SBP has a high WHC and therefore, an excess of pectins from SBP may trap bile acids and phospholipids in the chyme hindering the emulsification and absorption of dietary lipids (Lafont et al., 1985). Soluble fiber sources such as pectins decrease the rate of diffusion of glucose in small intestine (Johnson and Gee, 1981). Probably, the diffusion of lipid micelles in the small intestine is also inefficient under viscous conditions of the GIT. Thus, it is suggested that the inclusion of moderate amounts of a fiber source (less than 5%) to low fiber diets facilitate fat emulsification and absorption whereas an excess (7.5%) may have opposite effects (Smits et al., 1997; Jiménez-Moreno et al., 2011).

In conclusion, young broilers have a requirement for a minimal amount of fiber to optimize nutrient digestibility and growth but an excess of fiber reduces performance. The level of CF required for optimal performance ranges from 2.3 to 2.9% for OH and from 2.0 to 2.4% for SBP (8.5 to 10.1% total DF for OH and of 8.2 to 9.5% total DF for SBP) depending on the trait considered. High levels of fiber from these 2 sources (3.6 and 2.8% CF and 11.7 and 10.8% total DF for diets based on OH and SBP, respectively) reduce growth performance to values similar to those observed with the control diet. In general, the inclusion of OH is more beneficial for nutrient retention than the inclusion of SBP and lower levels of OH than of SBP are required to maximize retention in low fiber diets. Thus, under commercial conditions diets for young broilers should be formulated with a minimum and a maximum level of dietary fiber.

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**Table 1.** Chemical composition (%, as-fed basis unless otherwise indicated) and physical properties of oat hulls (OH) and sugar beet pulp (SBP)

| | OH | SBP |
|---|---|---|
| Chemical analysis[1] | | |
| Gross energy, kcal/kg | 4,160 | 3,689 |
| DM | 93.6 | 91.4 |
| CP | 3.0 | 8.9 |
| Starch | 9.2 | 1.0 |
| Ether extract | 1.4 | 1.1 |
| Total ash | 3.7 | 9.2 |
| Crude fiber | 28.3 | 17.8 |
| Neutral detergent fiber[2] | 70.2 | 34.2 |
| Acid detergent fiber[2] | 33.4 | 18.0 |
| Lignin acid detergent[2] | 3.7 | 1.8 |
| Total dietary fiber | 71.3 | 59.0 |
| Insoluble dietary fiber | 70.6 | 47.4 |
| Soluble dietary fiber | 0.7 | 11.6 |
| Physical properties | | |
| Screen size, $\mu$m | | |
| 1,250 | 3.3 | 26.6 |
| 630 | 41.2 | 47.2 |
| 315 | 35.3 | 15.2 |
| 160 | 15.4 | 6.5 |
| 80 | 5.7 | 4.5 |
| Geometric mean diameter, $\mu$m | 509 | 796 |
| GSD[3] | 1.9 | 2.1 |
| Water holding capacity, L/kg | 3.9 | 10.6 |
| SD | 0.51 | 0.08 |
| Swelling capacity, mL/g DM | 2.1 | 6.2 |
| SD | 0.40 | 0.78 |
| Lipid adsorption capacity, g | 2.1 | 1.3 |
| SD | 0.15 | 0.14 |

[1]Analyzed in triplicate samples.

[2]Neutral detergent fiber, acid detergent fiber, and lignin acid detergent were determined free of ash.

[3]Log normal geometric SD.

**Table 2.** Ingredient composition of the basal diet

| | Amount (%, as-fed basis) |
|---|---|
| Rice | 58.00 |
| Soy protein concentrate, 53% CP | 23.85 |
| Fish meal, 72% CP | 7.60 |
| Soy oil | 4.80 |
| Limestone | 1.00 |
| Dicalcium phosphate | 1.75 |
| Sodium chloride | 0.30 |
| DL-Met, 99% | 0.20 |
| Celite[1] | 2.00 |
| Vitamin and mineral premix[2] | 0.50 |

[1]Acid-washed diatomaceous earth (Celite Hispánica, S.A., Alicante, Spain).

[2]Provided the following (per kg of diet): vitamin A (transretinyl acetate), 10,000 IU; vitamin D3, (cholecalciferol), 2,000 IU; vitamin E (all-*rac*-tocopherol acetate), 20 IU; vitamin K (bisulphate menadione complex), 3 mg; riboflavin, 5 mg; pantothenic acid (D-calcium pantothenate), 10 mg; nicotinic acid, 30 mg; pyridoxine (pyridoxine·HCl), 3 mg; thiamin (thiamin-mononitrate), 1 mg; vitamin B12 (cyanocobalamine), 12 µg; D-biotin, 0.15 mg; choline (choline chloride), 300 mg; folic acid, 0.5 mg; Cu ($CuSO_4 \cdot 5H_2O$), 10 mg; Fe ($FeSO_4 \cdot 7H_2O$), 30 mg; Zn (ZnO), 100 mg; Mn ($MnSO_4 \cdot H_2O$), 100 mg; Se ($Na_2SeO_3$), 0.1 mg; I (KI), 2.0 mg; ethoxyquin, 110 mg.

548 **Table 3.** Chemical composition (%, as-fed basis unless otherwise indicated) and geometric mean diameter ($\mu$m) of the experimental diets

| | | Oat hulls | | | Sugar beet pulp | | |
|---|---|---|---|---|---|---|---|
| | Control | 2.5% | 5.0% | 7.5% | 2.5% | 5.0% | 7.5% |
| Calculated analysis[1] | | | | | | | |
| $AME_n$ (kcal/kg) | 3,250 | 3,180 | 3,108 | 3,037 | 3,190 | 3,133 | 3,074 |
| Digestible Lys | 1.24 | 1.21 | 1.18 | 1.15 | 1.22 | 1.19 | 1.16 |
| Digestible Met | 0.57 | 0.56 | 0.55 | 0.53 | 0.56 | 0.55 | 0.53 |
| Digestible Met + Cys | 0.90 | 0.87 | 0.85 | 0.83 | 0.87 | 0.85 | 0.83 |
| Digestible Thr | 0.80 | 0.78 | 0.77 | 0.75 | 0.79 | 0.77 | 0.75 |
| Ca | 1.07 | 1.05 | 1.02 | 1.00 | 1.07 | 1.07 | 1.06 |
| Available P | 0.45 | 0.44 | 0.43 | 0.42 | 0.44 | 0.43 | 0.42 |
| Determined analysis[2] | | | | | | | |
| Chemical analysis | | | | | | | |
| GE (kcal/kg) | 4,077 | 4,071 | 4,064 | 4,048 | 4,074 | 4,021 | 4,011 |
| CP | 21.9 | 21.2 | 21.1 | 20.7 | 21.5 | 21.2 | 20.8 |
| Starch | 43.7 | 42.8 | 41.7 | 40.7 | 42.6 | 41.4 | 40.3 |
| Ether extract | 5.5 | 5.1 | 4.8 | 4.6 | 5.5 | 5.3 | 5.0 |
| Total ash | 7.8 | 7.9 | 7.9 | 7.6 | 8.2 | 8.1 | 7.9 |
| Crude fiber | 1.6 | 2.3 | 2.9 | 3.6 | 2.0 | 2.4 | 2.8 |
| Neutral detergent fiber[3] | 4.2 | 5.1 | 7.1 | 9.4 | 4.9 | 5.3 | 6.8 |
| Acid detergent fiber[3] | 2.0 | 2.2 | 2.6 | 3.8 | 1.3 | 1.9 | 2.1 |
| Total dietary fiber | 6.9 | 8.5 | 10.1 | 11.7 | 8.2 | 9.5 | 10.8 |
| Insoluble dietary fiber | 4.2 | 5.9 | 7.6 | 9.3 | 5.3 | 6.4 | 7.5 |
| Soluble dietary fiber | 2.7 | 2.6 | 2.5 | 2.5 | 2.9 | 3.1 | 3.3 |
| Physical properties | | | | | | | |
| Screen size, $\mu$m | | | | | | | |
| 1,250 | 5.6 | 5.6 | 5.2 | 6.0 | 10.0 | 7.5 | 8.0 |
| 630 | 17.3 | 23.7 | 28.2 | 30.5 | 28.6 | 27.4 | 30.6 |
| 315 | 59.7 | 58.2 | 56.3 | 51.6 | 50.3 | 63.0 | 56.7 |
| 160 | 17.4 | 12.3 | 10.3 | 11.8 | 11.1 | 2.1 | 4.6 |
| 80 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Geometric mean diameter | 482 | 521 | 542 | 552 | 579 | 589 | 596 |
| GSD[4] | 1.7 | 1.7 | 1.6 | 1.7 | 1.8 | 1.6 | 1.6 |

549 [1]According to Fundación Española para el Desarrollo de la Nutrición Animal (2003).

[2]Analyzed in triplicate samples.

[3]Neutral detergent fiber and acid detergent fiber were determined free of ash.

[4]Log normal geometric SD.

**Table 4.** Effect of source [oat hulls (OH) and sugar beet pulp (SBP)] and level of inclusion (Level) of fiber of the diet on growth performance of broiler chicks from 1 to 18 d of age

| | | 1 to 6 d | | | 6 to 12 d | | | 12 to 18 d | | | 1 to 18 d | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Item | df | ADG[1] | ADFI[2] | F:G[3] | ADG | ADFI | F:G | ADG | ADFI | F:G | ADG | ADFI | F:G |
| Diet | | | | | | | | | | | | | |
| Control, 0% | | 17.2 | 19.5 | 1.139 | 31.5 | 41.6 | 1.324 | 42.0 | 64.6 | 1.544 | 31.0 | 43.2 | 1.396 |
| OH, 2.5% | | 16.7 | 19.1 | 1.143 | 31.2 | 40.9 | 1.316 | 42.7 | 62.9 | 1.476 | 31.0 | 42.3 | 1.365 |
| OH, 5.0% | | 17.3 | 19.6 | 1.133 | 30.8 | 38.3 | 1.241 | 41.3 | 63.3 | 1.535 | 30.5 | 41.6 | 1.363 |
| OH, 7.5% | | 15.8 | 18.3 | 1.158 | 29.7 | 38.4 | 1.292 | 42.1 | 65.2 | 1.550 | 30.0 | 41.9 | 1.398 |
| SBP, 2.5% | | 17.0 | 18.7 | 1.105 | 30.7 | 38.6 | 1.257 | 43.3 | 63.8 | 1.482 | 31.1 | 41.7 | 1.341 |
| SBP, 5.0% | | 16.2 | 18.5 | 1.138 | 29.6 | 37.5 | 1.261 | 43.6 | 64.9 | 1.493 | 30.6 | 41.6 | 1.357 |
| SBP, 7.5% | | 15.8 | 18.1 | 1.145 | 28.3 | 35.9 | 1.267 | 39.8 | 61.9 | 1.560 | 28.6 | 39.8 | 1.391 |
| SEM[4] | | 0.35 | 0.43 | 0.0142 | 1.01 | 1.56 | 0.0194 | 2.01 | 2.28 | 0.0321 | 0.99 | 1.26 | 0.0143 |
| Source of fiber | | | | | | | | | | | | | |
| OH | | 16.6 | 19.0 | 1.145 | 30.5 | 39.2 | 1.283 | 42.0 | 63.8 | 1.520 | 30.5 | 41.9 | 1.376 |
| SBP | | 16.3 | 18.4 | 1.129 | 29.5 | 37.3 | 1.262 | 42.2 | 63.5 | 1.512 | 30.1 | 41.0 | 1.363 |
| SEM[5] | | 0.20 | 0.25 | 0.0082 | 0.59 | 0.90 | 0.0112 | 1.16 | 1.31 | 0.0185 | 0.57 | 0.73 | 0.0082 |
| Level of fiber | | | | | | | | | | | | | |
| 2.5% | | 16.8 | 18.9 | 1.124 | 30.9 | 39.8 | 1.289 | 43.0 | 63.4 | 1.479 | 31.0 | 42.0 | 1.353 |
| 5.0% | | 16.7 | 19.0 | 1.136 | 30.2 | 37.9 | 1.251 | 42.4 | 64.1 | 1.514 | 30.6 | 41.6 | 1.360 |
| 7.5% | | 15.8 | 18.2 | 1.152 | 28.9 | 37.1 | 1.279 | 40.9 | 63.6 | 1.555 | 29.3 | 40.9 | 1.394 |
| SEM[6] | | 0.25 | 0.30 | 0.0100 | 0.72 | 1.10 | 0.0137 | 1.42 | 1.61 | 0.0227 | 0.70 | 0.89 | 0.0100 |
| Effect | | Probability | | | | | | | | | | | |
| Diet[7] | 6 | * | NS | NS | NS | NS | * | NS | NS | NS | NS | NS | 0.055 |
| C1 = Control vs. fiber | 1 | 0.063 | 0.084 | NS | NS | 0.054 | * | NS | NS | NS | NS | NS | 0.090 |
| C2 = Source | 1 | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS |
| C3 = Level[8] | 2 | L** | NS | L$^{0.060}$ | L$^{0.064}$ | NS | Q$^{0.068}$ | NS | NS | L* | L$^{0.097}$ | NS | L** |

[1]g.

[2]g.

[3]feed-to-gain ratio.

[4]$n = 6$ (12 birds per replicate).

[5]$n = 18$ (12 birds per replicate).

[6]$n = 12$ (12 birds per replicate).

[7]The interaction between type and level of fiber was not significant ($P > 0.10$).

[8]Linear (L) and quadratic (Q) contrasts for level of fiber effect (2.5, 5, and 7.5%).

*$P < 0.05$; ** $P < 0.01$; *** $P < 0.001$.

**Table 5.** Effect of source [oat hulls (OH) and sugar beet pulp (SBP)] and level of inclusion (Level) of fiber of the diet on energy efficiency (kcal $AME_n$ ingested /g BWG), water intake (g/d), water:feed intake ratio, and DM content (%) of the excreta of broilers

| | | Energy efficiency[1] | | | | Water intake | | Water:feed intake | | DM of the excreta, % | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Item* | df | 1 to 6 d | 6 to 12 d | 12 to 18 d | 1 to 18 d | 6 to 8 d | 16 to 18 d | 6 to 8 d | 16 to 18 d | 6 d | 12 d | 18 d | Average |
| Age | | | | | | | | | | 42.2 | 34.3 | 36.8 | |
| SEM[2] | | | | | | | | | | | | | 0.93 |
| Diet | | | | | | | | | | | | | |
| Control, 0% | | 3.67 | 4.22 | 4.95 | 4.48 | 70 | 111 | 1.90 | 2.08 | 43.7 | 36.8 | 39.1 | 39.9 |
| OH, 2.5% | | 3.70 | 4.27 | 4.84 | 4.44 | 70 | 117 | 1.88 | 2.16 | 43.5 | 35.1 | 37.8 | 38.8 |
| OH, 5.0% | | 3.62 | 3.93 | 4.87 | 4.33 | 69 | 112 | 1.86 | 2.07 | 45.8 | 39.4 | 42.5 | 42.5 |
| OH, 7.5% | | 3.59 | 3.97 | 4.81 | 4.32 | 63 | 110 | 1.71 | 1.99 | 48.5 | 39.8 | 43.0 | 43.8 |
| SBP, 2.5% | | 3.59 | 4.05 | 4.80 | 4.34 | 69 | 121 | 1.96 | 2.24 | 40.9 | 31.0 | 32.4 | 34.7 |
| SBP, 5.0% | | 3.57 | 3.94 | 4.71 | 4.26 | 71 | 122 | 2.01 | 2.31 | 39.5 | 30.9 | 32.2 | 34.2 |
| SBP, 7.5% | | 3.52 | 3.91 | 4.74 | 4.26 | 75 | 124 | 2.10 | 2.40 | 33.7 | 27.2 | 30.7 | 30.6 |
| SEM[3] | | 0.045 | 0.061 | 0.102 | 0.045 | 2.0 | 4.9 | 0.040 | 0.056 | | 2.45 | | 1.91 |
| Source of fiber | | | | | | | | | | | | | |
| OH | | 3.64 | 4.06 | 4.84 | 4.36 | 67 | 113 | 1.81 | 2.08 | 45.9 | 38.1 | 41.1 | 41.7 |
| SBP | | 3.56 | 3.96 | 4.75 | 4.29 | 72 | 122 | 2.02 | 2.32 | 38.1 | 29.7 | 31.8 | 33.6 |
| SEM[4] | | 0.026 | 0.035 | 0.059 | 0.026 | 1.2 | 2.8 | 0.023 | 0.032 | | 1.41 | | 1.28 |
| Level of fiber | | | | | | | | | | | | | |
| 2.5% | | 3.64 | 4.16 | 4.82 | 4.39 | 70 | 119 | 1.92 | 2.20 | 42.2 | 33.0 | 35.1 | 36.8 |
| 5.0% | | 3.59 | 3.93 | 4.79 | 4.30 | 70 | 117 | 1.93 | 2.19 | 42.6 | 35.2 | 37.3 | 38.4 |
| 7.5% | | 3.56 | 3.94 | 4.77 | 4.29 | 69 | 117 | 1.90 | 2.20 | 41.1 | 33.5 | 36.8 | 37.2 |
| SEM[5] | | 0.031 | 0.043 | 0.072 | 0.032 | 1.4 | 3.5 | 0.029 | 0.040 | | 1.73 | | 1.56 |
| Effect[6] | | Probability | | | | | | | | | | | |
| Age[7] | 2 | | | | | | | | | | | | L***, Q*** |
| Diet | 6 | NS | *** | NS | * | * | NS | *** | *** | | | | *** |
| C1 = Control vs. fiber | 1 | NS | ** | NS | ** | NS | NS | NS | 0.065 | | | | NS |
| C2 = Source | 1 | * | 0.068 | NS | * | ** | * | *** | *** | | | | *** |
| C3 = Level[8] | 2 | $L^{0.055}$ | L**, Q* | NS | L* | NS | NS | NS | NS | | | | NS |
| C4 = Source × level | 2 | NS | * | NS | NS | ** | NS | ** | * | | | | * |
| C4.1 = OH[9] | | - | L**, Q* | - | - | L* | - | L** | L* | | | | $L^{0.077}$ |
| C4.2 = SBP[10] | | - | NS | - | - | $L^{0.064}$ | - | L* | $L^{0.060}$ | | | | NS |

[1]Estimated $AME_n$ efficiency (kcal $AME_n$ ingested /g BWG). The $AME_n$ values were determined at 6 d of age for the 1 to 6 d of age period, at 12 d of age for the 6 to 12 d of age period, and at 18 d of age for the 12 to 18 d of age period. The average of values obtained at 6, 12, and 18 d of age was used to estimate the $AME_n$ of the diets for the entire experimental period.

[2]$n = 42$.

[3]$n = 6$ (12 birds per replicate).

[4]$n = 18$ (12 birds per replicate).

[5]$n = 12$ (12 birds per replicate).

[6]The interaction between diet and age was not significant for DM content of the excreta ($P > 0.10$).

[7]Linear (L) and quadratic (Q) contrasts for age effect.

[8]Linear (L) and quadratic (Q) contrasts for level of fiber effect (2.5, 5, and 7.5%).

[9]Linear (L) and quadratic (Q) contrasts for the OH diets.

[10]Linear (L) contrast for the SBP diets.

*$P < 0.05$; ** $P < 0.01$; *** $P < 0.001$.

**Table 6.** Effect of source [oat hulls (OH) and sugar beet pulp (SBP)] and level of inclusion (Level) of fiber of the diet on the relative weight of empty BW[1], gastrointestinal tract with digesta contents (full GIT)[2], liver, and pancreas (% BW) of broilers

| | | Empty BW | | | | Full GIT | | | | Liver | | | | Pancreas | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Item* | df | 6 d | 12 d | 18 d | Average | 6 d | 12 d | 18 d | Average | 6 d | 12 d | 18 d | Average | 6 d | 12 d | 18 d | Average |
| Age | | 74.5 | 80.8 | 84.5 | | 19.9 | 14.5 | 11.8 | | 4.96 | 3.37 | 2.75 | | 0.46 | 0.40 | 0.34 | |
| SEM[3] | | | | | 0.25 | | | | 0.16 | | | | 0.065 | | | | 0.007 |
| Diet | | | | | | | | | | | | | | | | | |
| Control, 0% | | 78.5 | 82.9 | 85.4 | 82.3 | 17.3 | 12.6 | 10.4 | 13.5 | 5.37 | 3.29 | 2.77 | 3.81 | 0.45 | 0.36 | 0.34 | 0.38 |
| OH, 2.5% | | 75.3 | 81.5 | 85.4 | 80.7 | 18.9 | 13.5 | 10.9 | 14.4 | 4.87 | 3.62 | 2.70 | 3.73 | 0.46 | 0.38 | 0.31 | 0.38 |
| OH, 5.0% | | 74.2 | 81.0 | 84.5 | 79.9 | 19.8 | 14.2 | 11.8 | 15.3 | 5.04 | 3.53 | 2.71 | 3.76 | 0.40 | 0.37 | 0.30 | 0.36 |
| OH, 7.5% | | 73.4 | 80.1 | 84.0 | 79.2 | 21.1 | 15.5 | 12.0 | 16.2 | 4.76 | 3.16 | 2.68 | 3.53 | 0.45 | 0.40 | 0.35 | 0.40 |
| SBP, 2.5% | | 75.6 | 80.7 | 84.7 | 80.3 | 19.1 | 14.4 | 11.7 | 15.1 | 4.70 | 3.31 | 2.78 | 3.60 | 0.46 | 0.41 | 0.33 | 0.40 |
| SBP, 5.0% | | 73.5 | 79.9 | 85.1 | 79.5 | 20.5 | 15.5 | 12.0 | 16.0 | 4.98 | 3.28 | 2.70 | 3.66 | 0.49 | 0.42 | 0.36 | 0.42 |
| SBP, 7.5% | | 71.4 | 79.5 | 82.4 | 77.8 | 22.8 | 16.0 | 13.6 | 17.4 | 4.96 | 3.41 | 2.89 | 3.75 | 0.53 | 0.44 | 0.38 | 0.45 |
| SEM[4] | | | 0.65 | | 0.38 | | 0.41 | | 0.24 | | 0.172 | | 0.099 | | 0.018 | | 0.011 |
| Source of fiber | | | | | | | | | | | | | | | | | |
| OH | | 74.3 | 80.9 | 84.6 | 79.9 | 19.9 | 14.8 | 11.6 | 15.3 | 4.89 | 3.43 | 2.70 | 3.67 | 0.44 | 0.38 | 0.32 | 0.38 |
| SBP | | 73.5 | 80.0 | 84.1 | 79.2 | 20.8 | 15.3 | 12.4 | 16.2 | 4.88 | 3.33 | 2.79 | 3.66 | 0.49 | 0.42 | 0.36 | 0.42 |
| SEM[5] | | | 0.37 | | 0.22 | | 0.24 | | 0.14 | | 0.100 | | 0.057 | | 0.011 | | 0.006 |
| Level of fiber | | | | | | | | | | | | | | | | | |
| 2.5% | | 75.4 | 81.1 | 85.1 | 80.5 | 19.0 | 14.0 | 11.3 | 14.8 | 4.79 | 3.46 | 2.74 | 3.66 | 0.46 | 0.39 | 0.32 | 0.39 |
| 5.0% | | 73.8 | 80.5 | 84.8 | 79.7 | 20.2 | 14.8 | 11.9 | 15.6 | 5.01 | 3.41 | 2.70 | 3.71 | 0.44 | 0.40 | 0.33 | 0.39 |
| 7.5% | | 72.4 | 79.8 | 83.2 | 78.5 | 22.0 | 15.7 | 12.8 | 16.8 | 4.86 | 3.28 | 2.78 | 3.64 | 0.49 | 0.42 | 0.36 | 0.42 |
| SEM[6] | | | 0.46 | | 0.27 | | 0.29 | | 0.17 | | 0.122 | | 0.070 | | 0.013 | | 0.008 |
| Effect[7] | | | | | | | | | Probability | | | | | | | | |
| Age[8] | 2 | | | | L***, Q*** | | | | L***, Q*** | | | | L***, Q*** | | | | L*** |
| Diet | 6 | | | | *** | | | | *** | | | | NS | | | | *** |
| C1 = Control vs. fiber | 1 | | | | *** | | | | *** | | | | NS | | | | 0.075 |
| C2 = Source | 1 | | | | * | | | | *** | | | | NS | | | | *** |
| C3 = Level[9] | 2 | | | | L*** | | | | L*** | | | | NS | | | | L**, $Q^{0.062}$ |
| C4 = Source × level | 2 | | | | NS | | | | NS | | | | NS | | | | 0.073 |
| C4.1 = OH[10] | | | | | - | | | | - | | | | - | | | | Q* |
| C4.2 = SBP[11] | | | | | - | | | | - | | | | - | | | | L** |

[1]Empty body weight without the liver, pancreas, and the digestive tract with contents.

[2]From end of the crop to the cloaca.

[3]$n = 42$.

[4]$n = 6$ for the mean within each day and $n = 18$ for the average value at 6, 12, and 18 d.

[5]$n = 18$ for the mean within each day and $n = 54$ for the average value at 6, 12, and 18 d.

[6]$n = 12$ for the mean within each day and $n = 36$ for the average value at 6, 12, and 18 d.

[7]The interaction between diet and age was not significant ($P > 0.10$).

[8]Linear (L) and quadratic (Q) contrasts for age effect.

[9]Linear (L) and quadratic (Q) contrasts for level of fiber effect (2.5, 5, and 7.5%).

[10]Linear (L) and quadratic (Q) contrast for the OH diets.

[11]Linear (L) contrast for the SBP diets.

*$P < 0.05$; ** $P < 0.01$; *** $P < 0.001$.

**Table 7.** Effect of source [oat hulls (OH) and sugar beet pulp (SBP)] and level of inclusion (Level) of fiber of the diet on the relative empty weight (% BW) of proventriculus, gizzard, and ceca of broilers

| | | Proventriculus | | | | Gizzard | | | | Ceca | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Item* | df | 6 d | 12 d | 18 d | Average | 6 d | 12 d | 18 d | Average | 6 d | 12 d | 18 d | Average |
| Age | | 1.04 | 0.66 | 0.52 | | 4.38 | 2.65 | 2.12 | | 0.57 | 0.48 | 0.50 | |
| SEM[1] | | | | | 0.009 | | | | 0.049 | | | | 0.011 |
| Diet | | | | | | | | | | | | | |
| Control, 0% | | 0.94 | 0.59 | 0.46 | 0.66 | 3.19 | 1.76 | 1.17 | 2.04 | 0.58 | 0.45 | 0.44 | 0.49 |
| OH, 2.5% | | 0.99 | 0.60 | 0.49 | 0.70 | 4.61 | 2.75 | 2.35 | 3.24 | 0.57 | 0.44 | 0.47 | 0.50 |
| OH, 5.0% | | 0.98 | 0.65 | 0.51 | 0.71 | 5.02 | 3.02 | 2.80 | 3.62 | 0.55 | 0.44 | 0.49 | 0.49 |
| OH, 7.5% | | 1.08 | 0.67 | 0.55 | 0.77 | 5.56 | 3.73 | 3.05 | 4.11 | 0.55 | 0.46 | 0.51 | 0.51 |
| SBP, 2.5% | | 1.04 | 0.68 | 0.52 | 0.75 | 3.82 | 2.12 | 1.57 | 2.50 | 0.54 | 0.51 | 0.55 | 0.53 |
| SBP, 5.0% | | 1.11 | 0.71 | 0.54 | 0.79 | 3.98 | 2.52 | 1.85 | 2.78 | 0.57 | 0.56 | 0.51 | 0.55 |
| SBP, 7.5% | | 1.16 | 0.73 | 0.59 | 0.83 | 4.45 | 2.64 | 2.03 | 3.04 | 0.62 | 0.51 | 0.51 | 0.55 |
| SEM[2] | | | 0.024 | | 0.013 | | 0.131 | | 0.075 | | 0.028 | | 0.016 |
| Source of fiber | | | | | | | | | | | | | |
| OH | | 1.02 | 0.64 | 0.52 | 0.72 | 5.06 | 3.17 | 2.73 | 3.66 | 0.56 | 0.45 | 0.49 | 0.50 |
| SBP | | 1.10 | 0.71 | 0.55 | 0.79 | 4.09 | 2.43 | 1.81 | 2.77 | 0.58 | 0.52 | 0.53 | 0.54 |
| SEM[3] | | | 0.014 | | 0.008 | | 0.075 | | 0.044 | | 0.016 | | 0.009 |
| Level of fiber | | | | | | | | | | | | | |
| 2.5% | | 1.02 | 0.64 | 0.51 | 0.72 | 4.22 | 2.43 | 1.95 | 2.87 | 0.56 | 0.48 | 0.51 | 0.51 |
| 5.0% | | 1.04 | 0.68 | 0.52 | 0.75 | 4.50 | 2.77 | 2.32 | 3.20 | 0.56 | 0.50 | 0.50 | 0.52 |
| 7.5% | | 1.12 | 0.70 | 0.57 | 0.80 | 5.00 | 3.19 | 2.54 | 3.60 | 0.58 | 0.48 | 0.51 | 0.53 |
| SEM[4] | | | 0.017 | | 0.009 | | 0.093 | | 0.053 | | 0.020 | | 0.011 |
| Effect[5] | | Probability | | | | | | | | | | | |
| Age[6] | 2 | | | | L***, Q*** | | | | L***, Q*** | | | | L***, Q*** |
| Diet | 6 | | | | *** | | | | *** | | | | * |
| C1 = Control vs. fiber | 1 | | | | *** | | | | *** | | | | 0.071 |
| C2 = Source | 1 | | | | *** | | | | *** | | | | ** |
| C3 = Level[7] | 2 | | | | L*** | | | | L*** | | | | NS |
| C4 = Source × level | 2 | | | | NS | | | | 0.084 | | | | NS |
| C4.1 = OH[8] | | | | | - | | | | L*** | | | | - |

| | | | |
|---|---|---|---|
| C4.2 = SBP[9] | - | L*** | - |

[1]$n = 42$.

[2]$n = 6$ for the mean within each day and $n = 18$ for the average value at 6, 12, and 18 d.

[3]$n = 18$ for the mean within each day and $n = 54$ for the average value at 6, 12, and 18 d.

[4]$n = 12$ for the mean within each day and $n = 36$ for the average value at 6, 12, and 18 d.

[5]The interaction between diet and age was not significant ($P > 0.10$).

[6]Linear (L) and quadratic (Q) contrasts for age effect.

[7]Linear (L) contrast for level of fiber effect (2.5, 5, and 7.5%).

[8]Linear (L) contrast for the OH diets.

[9]Linear (L) contrast for the SBP diets.

*$P < 0.05$; ** $P < 0.01$; *** $P < 0.001$.

**Table 8**. Effect of source [oat hulls (OH) and sugar beet pulp (SBP)] and level of inclusion (Level) of fiber of the diet on the relative weight (RW, g/kg BW) of the fresh digesta contents of proventriculus, gizzard, and ceca, and total DM content (g DM/ kg BW) of the gizzard digesta of broilers

| | | Proventriculus | | | | Gizzard | | | | | Ceca | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Digesta content | | | | Digesta content | | | | DM content | Digesta content | | | |
| *Item* | df | 6 d | 12 d | 18 d | Average | 6 d | 12 d | 18 d | Average | 18 d | 6 d | 12 d | 18 d | Average |
| Age | | 0.119 | 0.075 | 0.046 | | 2.16 | 1.43 | 1.06 | | | 0.44 | 0.57 | 0.36 | |
| SEM[1] | | | | | 0.0066 | | | | 0.052 | | | | | 0.032 |
| Treatments | | | | | | | | | | | | | | |
| Control, 0% | | 0.148 | 0.097 | 0.058 | 0.101 | 0.64 | 0.42 | 0.18 | 0.41 | 1.39 | 0.18 | 0.45 | 0.28 | 0.30 |
| OH, 2.5% | | 0.062 | 0.055 | 0.027 | 0.048 | 1.93 | 1.23 | 0.94 | 1.37 | 3.53 | 0.44 | 0.44 | 0.37 | 0.42 |
| OH, 5.0% | | 0.100 | 0.052 | 0.030 | 0.061 | 2.20 | 1.44 | 1.15 | 1.60 | 4.15 | 0.43 | 0.65 | 0.38 | 0.49 |
| OH, 7.5% | | 0.088 | 0.043 | 0.032 | 0.054 | 2.86 | 1.68 | 1.13 | 1.89 | 4.27 | 0.38 | 0.59 | 0.36 | 0.44 |
| SBP, 2.5% | | 0.155 | 0.132 | 0.078 | 0.122 | 2.13 | 1.49 | 1.04 | 1.55 | 1.82 | 0.56 | 0.50 | 0.38 | 0.48 |
| SBP, 5.0% | | 0.143 | 0.085 | 0.042 | 0.090 | 2.47 | 1.76 | 1.27 | 1.83 | 2.30 | 0.52 | 0.73 | 0.44 | 0.56 |
| SBP, 7.5% | | 0.137 | 0.063 | 0.058 | 0.086 | 2.89 | 2.02 | 1.69 | 2.20 | 2.75 | 0.57 | 0.67 | 0.33 | 0.52 |
| SEM[2] | | | 0.0175 | | 0.0110 | 0.177 | 0.130 | 0.097 | 0.080 | 0.372 | | 0.084 | | 0.048 |
| Source of fiber | | | | | | | | | | | | | | |
| OH | | 0.083 | 0.050 | 0.029 | 0.054 | 2.33 | 1.45 | 1.07 | 1.62 | 3.98 | 0.42 | 0.56 | 0.37 | 0.45 |
| SBP | | 0.145 | 0.093 | 0.059 | 0.099 | 2.50 | 1.75 | 1.33 | 1.86 | 2.29 | 0.55 | 0.63 | 0.38 | 0.52 |
| SEM[3] | | | 0.0100 | | 0.0058 | 0.102 | 0.075 | 0.056 | 0.046 | 0.215 | | 0.048 | | 0.028 |
| Level of fiber | | | | | | | | | | | | | | |
| 2.5% | | 0.108 | 0.093 | 0.052 | 0.085 | 2.03 | 1.36 | 0.99 | 1.46 | 2.67 | 0.50 | 0.47 | 0.38 | 0.45 |
| 5.0% | | 0.122 | 0.068 | 0.036 | 0.075 | 2.34 | 1.59 | 1.21 | 1.71 | 3.23 | 0.47 | 0.69 | 0.41 | 0.53 |
| 7.5% | | 0.112 | 0.053 | 0.045 | 0.070 | 2.87 | 1.85 | 1.41 | 2.04 | 3.51 | 0.48 | 0.63 | 0.35 | 0.48 |
| SEM[4] | | | 0.0124 | | 0.0071 | 0.125 | 0.092 | 0.069 | 0.057 | 0.26 | | 0.059 | | 0.034 |
| Effect | | Probability | | | | | | | | | | | | |
| Age[5] | 2 | | | | L*** | | | | L***,Q** | - | | | | $L^{0.086}$, Q*** |
| Diet | 6 | | | | *** | *** | *** | *** | *** | *** | | | | ** |
| C1 = Control vs. fiber | 1 | | | | * | *** | *** | *** | | *** | | | | *** |
| C2 = Source | 1 | | | | *** | NS | ** | ** | | *** | | | | 0.075 |
| C3 = Level[6] | 2 | | | | NS | L*** | L*** | L*** | | L* | | | | NS |
| C4 = Source × level | 2 | | | | 0.051 | NS | NS | * | | NS | | | | NS |
| C4.1 = OH[7] | | | | | NS | - | - | NS | | - | | | | - |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| C4.2 = SBP[8] | | L* | - | - | L*** | - | - | - |
| Diet × age | 12 | NS | | | | * | - | NS |

[1]$n = 42$.

[2]$n = 6$ for the mean within each day and $n = 18$ for the average value at 6, 12, and 18 d.

[3]$n = 18$ for the mean within each day and $n = 54$ for the average value at 6, 12, and 18 d.

[4]$n = 12$ for the mean within each day and $n = 36$ for the average value at 6, 12, and 18 d.

[5]Linear (L) and quadratic (Q) contrasts for age effect.

[6]Linear (L) contrast for level of fiber effect (2.5, 5, and 7.5%).

[7]Linear (L) contrast for the OH diets.

[8]Linear (L) contrast for the SBP diets.

$^{*}P < 0.05$; $^{**}P < 0.01$; $^{***}P < 0.001$.

**Table 9.** Effect of source [oat hulls (OH) and sugar beet pulp (SBP)] and level of inclusion (Level) of fiber of the diet on the relative length of small intestine and ceca (cm/kg empty BW) of broilers

| | | Small intestine | | | | Ceca | | | |
|---|---|---|---|---|---|---|---|---|---|
| *Item* | df | 6 d | 12 d | 18 d | Average | 6 d | 12 d | 18 d | Average |
| Age | | 445 | 406 | 132 | | 72.4 | 36.2 | 26.3 | |
| SEM[1] | | | | | 4.2 | | | | 0.64 |
| Diet | | | | | | | | | |
| Control, 0% | | 434 | 407 | 125 | 322 | 64.7 | 36.7 | 22.8 | 41.4 |
| OH, 2.5% | | 433 | 388 | 133 | 318 | 72.2 | 32.5 | 26.2 | 43.6 |
| OH, 5.0% | | 431 | 379 | 128 | 313 | 70.3 | 35.0 | 26.7 | 44.0 |
| OH, 7.5% | | 448 | 392 | 141 | 327 | 73.5 | 37.8 | 29.2 | 46.8 |
| SBP, 2.5% | | 447 | 423 | 130 | 333 | 71.2 | 34.2 | 25.8 | 43.7 |
| SBP, 5.0% | | 467 | 416 | 129 | 338 | 76.7 | 38.2 | 26.7 | 47.2 |
| SBP, 7.5% | | 458 | 436 | 140 | 345 | 77.2 | 39.0 | 26.9 | 47.7 |
| SEM[2] | | | 11.2 | | 6.5 | 2.34 | 1.47 | 1.00 | 0.98 |
| Source of fiber | | | | | | | | | |
| OH | | 437 | 386 | 134 | 319 | 72.0 | 35.1 | 27.3 | 44.8 |
| SBP | | 458 | 425 | 133 | 339 | 75.0 | 37.1 | 26.4 | 46.2 |
| SEM[3] | | | 6.5 | | 3.7 | 1.35 | 0.85 | 0.57 | 0.56 |
| Level of fiber | | | | | | | | | |
| 2.5% | | 440 | 406 | 131 | 326 | 71.7 | 33.3 | 26.0 | 43.7 |
| 5.0% | | 449 | 398 | 129 | 325 | 73.5 | 36.6 | 26.7 | 45.6 |
| 7.5% | | 453 | 414 | 141 | 336 | 75.3 | 38.4 | 28.0 | 47.2 |
| SEM[4] | | | 7.9 | | 4.6 | 1.65 | 1.04 | 0.70 | 0.69 |
| Effect | | Probability | | | | | | | |
| Age[5] | 2 | | | | L***, Q*** | | | | L***, Q*** |
| Diet[6] | 6 | | | | ** | * | * | ** | *** |
| C1 = Control vs. fiber | 1 | | | | NS | ** | NS | *** | |
| C2 = Source | 1 | | | | ** | NS | NS | NS | |
| C3 = Level[7] | 2 | | | | L* | NS | L** | NS | |

| | | | |
|---|---|---|---|
| Diet × age | 12 | NS | * |

[1]$n = 42$.

[2]$n = 6$ for the mean within each day and $n = 18$ for the average value at 6, 12, and 18 d.

[3]$n = 18$ for the mean within each day and $n = 54$ for the average value at 6, 12, and 18 d.

[4]$n = 12$ for the mean within each day and $n = 36$ for the average value at 6, 12, and 18 d.

[5]Linear (L) and quadratic (Q) contrasts for age effect.

[6]The interaction between source and level of fiber was not significant ($P > 0.10$) for both relative length of the small intestine and ceca, and the interaction among source and level of fiber and age for the relative length of the ceca was not significant ($P > 0.10$).

[7]Linear (L) contrast for level of fiber effect (2.5, 5, and 7.5%).

*$P < 0.05$; ** $P < 0.01$; *** $P < 0.001$.

**Table 10.** Effect of source [oat hulls (OH) and sugar beet pulp (SBP)] and level of inclusion (Level) of fiber of the diet on the pH of the digesta of the proventriculus, gizzard, and duodenum of broilers

| | | Proventriculus pH | | | | Gizzard pH | | | | Duodenum pH | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Item* | df | 6 d | 12 d | 18 d | Average | 6 d | 12 d | 18 d | Average | 6 d | 12 d | 18 d | Average |
| Age | | 4.27 | 4.05 | 3.81 | | 3.15 | 2.94 | 2.80 | | 6.29 | 6.26 | 6.14 | |
| SEM[1] | | | | | 0.053 | | | | 0.048 | | | | 0.020 |
| Diet | | | | | | | | | | | | | |
| Control, 0% | | 4.51 | 4.45 | 4.32 | 4.43 | 3.98 | 3.89 | 3.70 | 3.86 | 6.19 | 6.20 | 5.98 | 6.12 |
| OH, 2.5% | | 4.23 | 4.15 | 3.84 | 4.07 | 3.15 | 3.12 | 2.80 | 3.02 | 6.21 | 6.21 | 6.16 | 6.19 |
| OH, 5.0% | | 4.27 | 4.18 | 3.88 | 4.11 | 3.09 | 2.90 | 2.63 | 2.92 | 6.27 | 6.17 | 6.21 | 6.22 |
| OH, 7.5% | | 4.31 | 4.20 | 3.92 | 4.14 | 2.97 | 2.77 | 2.75 | 2.83 | 6.28 | 6.25 | 6.17 | 6.23 |
| SBP, 2.5% | | 3.99 | 3.60 | 3.37 | 3.65 | 3.02 | 2.81 | 2.63 | 2.82 | 6.30 | 6.25 | 6.13 | 6.23 |
| SBP, 5.0% | | 4.27 | 3.71 | 3.63 | 3.87 | 2.92 | 2.64 | 2.59 | 2.72 | 6.37 | 6.38 | 6.23 | 6.33 |
| SBP, 7.5% | | 4.32 | 4.07 | 3.73 | 4.04 | 2.90 | 2.48 | 2.38 | 2.59 | 6.40 | 6.39 | 6.14 | 6.31 |
| SEM[2] | | | 0.141 | | 0.081 | | 0.126 | | 0.073 | | 0.053 | | 0.030 |
| Source of fiber | | | | | | | | | | | | | |
| OH | | 4.27 | 4.18 | 3.88 | 4.11 | 3.07 | 2.93 | 2.77 | 2.92 | 6.25 | 6.21 | 6.18 | 6.21 |
| SBP | | 4.19 | 3.79 | 3.58 | 3.85 | 2.95 | 2.64 | 2.53 | 2.71 | 6.36 | 6.34 | 6.16 | 6.29 |
| SEM[3] | | | 0.081 | | 0.047 | | 0.073 | | 0.042 | | 0.030 | | 0.018 |
| Level of fiber | | | | | | | | | | | | | |
| 2.5% | | 4.11 | 3.87 | 3.60 | 3.86 | 3.09 | 2.96 | 2.71 | 2.92 | 6.25 | 6.23 | 6.14 | 6.21 |
| 5.0% | | 4.27 | 3.95 | 3.75 | 3.99 | 3.01 | 2.77 | 2.68 | 2.82 | 6.32 | 6.28 | 6.22 | 6.27 |
| 7.5% | | 4.31 | 4.13 | 3.83 | 4.09 | 2.93 | 2.62 | 2.56 | 2.71 | 6.34 | 6.32 | 6.15 | 6.27 |
| SEM[4] | | | 0.100 | | 0.058 | | 0.089 | | 0.052 | | 0.037 | | 0.022 |
| Effect[5] | | Probability | | | | | | | | | | | |
| Age[6] | 2 | | | | L***, Q*** | | | | L*** | | | | L***, $Q^{0.051}$ |
| Diet | 6 | | | | *** | | | | *** | | | | *** |
| C1 = Control vs. fiber | 1 | | | | *** | | | | *** | | | | *** |
| C2 = Source | 1 | | | | *** | | | | *** | | | | ** |
| C3 = Level[7] | 2 | | | | L** | | | | L** | | | | L* |

[1]$n = 42$.

[2]$n = 6$ for the mean within each day and $n = 18$ for the average value at 6, 12, and 18 d.

[3]$n = 18$ for the mean within each day and $n = 54$ for the average value at 6, 12, and 18 d.

[4]$n = 12$ for the mean within each day and $n = 36$ for the average value at 6, 12, and 18 d.

[5]The remaining interactions were not significant ($P > 0.10$).

[6]Linear (L) and quadratic (Q) contrasts for age effect.

[7]Linear (L) contrast for the level of fiber effect (2.5, 5, and 7.5%).

*$P < 0.05$; ** $P < 0.01$; *** $P < 0.001$.

**Table 11.** Effect of source [oat hulls (OH) and sugar beet pulp (SBP)] and level of inclusion (Level) of fiber of the diet on the jejunal morphology of broilers

| | | Villus height, $\mu$m | | | Crypt depth, $\mu$m | | | Villus height: crypt depth ratio | | |
|---|---|---|---|---|---|---|---|---|---|---|
| *Item* | df | 12 d | 18 d | Average | 12 d | 18 d | Average | 12 d | 18 d | Average |
| Age | | 786 | 818 | | 124 | 106 | | 6.67 | 8.11 | |
| SEM[1] | | | | 24.5 | | | 3.01 | | | 0.165 |
| Diet | | | | | | | | | | |
| Control, 0% | | 918 | 774 | 846 | 143 | 108 | 125 | 6.83 | 7.59 | 7.21 |
| OH, 2.5% | | 841 | 830 | 836 | 130 | 108 | 119 | 6.85 | 8.02 | 7.44 |
| OH, 5.0% | | 914 | 967 | 940 | 136 | 115 | 126 | 7.07 | 8.93 | 8.00 |
| OH, 7.5% | | 709 | 827 | 768 | 113 | 106 | 109 | 6.58 | 8.21 | 7.40 |
| SBP, 2.5% | | 734 | 835 | 785 | 114 | 104 | 109 | 6.95 | 8.58 | 7.76 |
| SBP, 5.0% | | 764 | 756 | 760 | 116 | 102 | 108 | 6.76 | 7.70 | 7.23 |
| SBP, 7.5% | | 619 | 737 | 678 | 115 | 101 | 108 | 5.65 | 7.70 | 6.67 |
| SEM[2] | | | 64.7 | 45.8 | | 8.0 | 5.6 | | 0.437 | 0.309 |
| Source of fiber | | | | | | | | | | |
| OH | | 822 | 878 | 848 | 126 | 110 | 118 | 6.84 | 8.39 | 7.61 |
| SBP | | 706 | 776 | 741 | 115 | 102 | 109 | 6.45 | 7.99 | 7.22 |
| SEM[3] | | | 37.4 | 26.4 | | 4.6 | 3.2 | | 0.252 | 0.178 |
| Level of fiber | | | | | | | | | | |
| 2.5% | | 788 | 833 | 810 | 122 | 106 | 114 | 6.90 | 8.30 | 7.60 |
| 5.0% | | 839 | 867 | 850 | 126 | 108 | 117 | 6.91 | 8.32 | 7.61 |
| 7.5% | | 664 | 782 | 723 | 114 | 103 | 108 | 6.12 | 7.96 | 7.04 |
| SEM[4] | | | 45.8 | 32.4 | | 5.6 | 3.9 | | 0.309 | 0.218 |
| Effect[5] | | Probability | | | | | | | | |
| Age | 1 | | | NS | | | *** | | | *** |
| Diet | 6 | | | ** | | | 0.068 | | | 0.094 |
| C1 = Control vs. fiber | 1 | | | NS | | | 0.051 | | | NS |
| C2 = Source | 1 | | | ** | | | * | | | NS |
| C3 = Level[6] | 2 | | | $L^{0.061}$; Q* | | | NS | | | $L^{0.072}$ |

[1] $n = 42$.

[2]$n = 6$ for the mean within each day and $n = 12$ for the average value at 6, 12, and 18 d.

[3]$n = 18$ for the mean within each day and $n = 36$ for the average value at 6, 12, and 18 d.

[4]$n = 12$ for the mean within each day and $n = 24$ for the average value at 6, 12, and 18 d.

[5]The remaining interactions were not significant ($P > 0.10$).

[6]Linear (L) and quadratic (Q) contrasts for level of fiber effect (2.5, 5, and 7.5%).

*$P < 0.05$; ** $P < 0.01$; *** $P < 0.001$.

**Table 12.** Effect of source [oat hulls (OH) and sugar beet pulp (SBP)] and level of inclusion (Level) of fiber of the diet on the total tract apparent retention (%) of DM, organic matter, and nitrogen of broiler

| | | DM | | | | Organic matter | | | | Nitrogen | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Item* | df | 6 d | 12 d | 18 d | Average | 6 d | 12 d | 18 d | Average | 6 d | 12 d | 18 d | Average |
| Age | | 77.3 | 77.0 | 77.1 | | 81.4 | 81.5 | 81.6 | | 63.6 | 63.8 | 65.5 | |
| SEM[1] | | 0.15 | 0.12 | 0.11 | | 0.13 | 0.13 | 0.10 | | 0.29 | 0.26 | 0.24 | |
| Diet | | | | | | | | | | | | | |
| Control, 0% | | 78.2 | 77.3 | 77.8 | 77.8 | 82.5 | 82.2 | 82.4 | 82.4 | 63.1 | 61.8 | 63.5 | 62.8 |
| OH, 2.5% | | 78.7 | 79.2 | 79.7 | 79.2 | 82.7 | 83.7 | 84.1 | 83.5 | 65.3 | 67.4 | 69.0 | 67.3 |
| OH, 5.0% | | 77.6 | 77.0 | 76.8 | 77.2 | 81.6 | 81.4 | 81.2 | 81.4 | 66.3 | 66.6 | 66.8 | 66.6 |
| OH, 7.5% | | 75.5 | 75.1 | 75.5 | 75.4 | 79.3 | 79.3 | 79.7 | 79.4 | 64.4 | 65.2 | 67.3 | 65.6 |
| SBP, 2.5% | | 78.7 | 78.0 | 78.5 | 78.4 | 83.0 | 82.5 | 83.1 | 82.9 | 63.0 | 63.1 | 65.9 | 64.0 |
| SBP, 5.0% | | 77.1 | 76.8 | 77.4 | 77.1 | 81.1 | 81.4 | 81.9 | 81.4 | 63.4 | 62.4 | 64.8 | 63.5 |
| SBP, 7.5% | | 75.4 | 75.5 | 74.2 | 75.0 | 79.7 | 79.6 | 78.6 | 79.5 | 59.7 | 59.9 | 61.3 | 60.3 |
| SEM[2] | | 0.39 | 0.34 | 0.32 | 0.21 | 0.37 | 0.37 | 0.33 | 0.21 | 0.78 | 0.70 | 0.64 | 0.46 |
| Source of fiber | | | | | | | | | | | | | |
| OH | | 77.3 | 77.1 | 77.3 | 77.2 | 81.2 | 81.4 | 81.7 | 81.4 | 65.3 | 66.4 | 67.7 | 66.5 |
| SBP | | 77.1 | 76.8 | 76.7 | 76.8 | 81.2 | 81.4 | 81.2 | 81.3 | 62.0 | 61.8 | 64.0 | 62.6 |
| SEM[3] | | 0.23 | 0.19 | 0.18 | 0.12 | 0.21 | 0.21 | 0.19 | 0.12 | 0.45 | 0.40 | 0.37 | 0.27 |
| Level of fiber | | | | | | | | | | | | | |
| 2.5% | | 78.7 | 78.6 | 79.1 | 78.8 | 82.8 | 83.1 | 83.6 | 83.2 | 64.2 | 65.3 | 67.5 | 65.6 |
| 5.0% | | 77.4 | 76.9 | 77.1 | 77.1 | 81.3 | 81.4 | 81.5 | 81.4 | 64.8 | 64.5 | 65.8 | 65.0 |
| 7.5% | | 75.4 | 75.3 | 74.9 | 75.2 | 79.5 | 79.8 | 79.2 | 79.5 | 62.0 | 62.5 | 64.3 | 63.0 |
| SEM[4] | | 0.28 | 0.24 | 0.23 | 0.15 | 0.26 | 0.26 | 0.23 | 0.17 | 0.55 | 0.49 | 0.45 | 0.33 |
| Effect | | Probability | | | | | | | | | | | |
| Age[5] | 2 | | | | NS | | | | NS | | | | L***, Q** |
| Diet | 6 | *** | *** | *** | *** | *** | *** | *** | *** | | | | *** |
| C1 = Control vs. fiber | 1 | * | NS | * | | ** | 0.071 | ** | | | | | ** |
| C2 = Source | 1 | NS | NS | * | | NS | NS | 0.096 | | | | | *** |
| C3 = Level[6] | 2 | L*** | L*** | L*** | | L*** | L*** | L*** | | | | | L***, $Q^{0.069}$ |
| C4 = Source × level | 2 | NS | 0.064 | ** | | NS | * | * | | | | | ** |
| C4.1 = OH[7] | | - | L*** | L***, $Q^{0.057}$ | | - | L*** | L***, $Q^{0.066}$ | | | | | L* |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| C4.2 = SBP[8] | - | L*** | L***, Q** | | - | L*** | L***, Q* | | L***, Q* |
| Diet × age | 12 | | | * | | | | ** | NS |

[1]$n = 42$.

[2]$n = 6$ for the mean within each day and $n = 18$ for the average value at 6, 12, and 18 d.

[3]$n = 18$ for the mean within each day and $n = 54$ for the average value at 6, 12, and 18 d.

[4]$n = 12$ for the mean within each day and $n = 36$ for the average value at 6, 12, and 18 d.

[5]Linear (L) and quadratic (Q) contrasts for age effect.

[6]Linear (L) and quadratic (Q) contrasts for level of fiber effect (2.5, 5, and 7.5%).

[7]Linear (L) contrast for the OH diets.

[8]Linear (L) and quadratic (Q) contrasts for the SBP diets.

*$P < 0.05$; ** $P < 0.01$; *** $P < 0.001$.

**Table 13.** Effect of source [oat hulls (OH) and sugar beet pulp (SBP)] and level of inclusion (Level) of fiber of the diet on the total tract apparent retention (%) of soluble ash, extract ether, and $AME_n$ (kcal/kg) of the diet in broilers

| | | Soluble ash | | | | Ether extract | | | | $AME_n$ | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Item* | df | 6 d | 12 d | 18 d | Average | 6 d | 12 d | 18 d | Average | 6 d | 12 d | 18 d | Average |
| Age | | 48.3 | 42.0 | 43.7 | | 90.9 | 90.5 | 91.8 | | 3,173 | 3,158 | 3,170 | |
| SEM[1] | | 0.76 | 0.50 | 0.43 | | 0.11 | 0.11 | 0.18 | | 4.7 | 4.0 | 4.0 | |
| Diet | | | | | | | | | | | | | |
| Control, 0% | | 44.8 | 39.0 | 40.2 | 41.3 | 91.6 | 90.9 | 91.2 | 91.3 | 3,218 | 3,191 | 3,209 | 3,206 |
| OH, 2.5% | | 49.7 | 43.8 | 45.9 | 46.5 | 91.8 | 92.3 | 93.5 | 92.5 | 3,236 | 3,247 | 3,276 | 3,253 |
| OH, 5.0% | | 51.1 | 44.7 | 45.1 | 47.0 | 91.7 | 91.3 | 92.3 | 91.8 | 3,192 | 3,166 | 3,171 | 3,177 |
| OH, 7.5% | | 49.4 | 42.5 | 44.3 | 45.4 | 90.5 | 90.0 | 91.2 | 90.6 | 3,102 | 3,076 | 3,100 | 3,093 |
| SBP, 2.5% | | 48.6 | 44.2 | 45.8 | 46.2 | 91.4 | 91.2 | 92.5 | 91.7 | 3,251 | 3,222 | 3,238 | 3,237 |
| SBP, 5.0% | | 50.5 | 42.5 | 44.9 | 46.0 | 90.4 | 89.7 | 91.4 | 90.5 | 3,136 | 3,123 | 3,157 | 3,139 |
| SBP, 7.5% | | 44.0 | 37.5 | 39.5 | 40.3 | 88.6 | 88.2 | 90.5 | 89.1 | 3,074 | 3,083 | 3,039 | 3,066 |
| SEM[2] | | 2.02 | 1.32 | 1.11 | 0.93 | 0.30 | 0.28 | 0.49 | 0.24 | 13.0 | 11.8 | 12.0 | 7.3 |
| Source of fiber | | | | | | | | | | | | | |
| OH | | 50.1 | 43.6 | 45.1 | 46.3 | 91.3 | 91.2 | 92.3 | 91.6 | 3,177 | 3,163 | 3,183 | 3,174 |
| SBP | | 47.7 | 41.4 | 43.4 | 44.2 | 90.1 | 89.7 | 91.5 | 90.4 | 3,154 | 3,143 | 3,145 | 3,147 |
| SEM[3] | | 1.17 | 0.76 | 0.65 | 0.54 | 0.17 | 0.16 | 0.28 | 0.14 | 7.5 | 6.8 | 6.9 | 4.2 |
| Level of fiber inclusion | | | | | | | | | | | | | |
| 2.5% | | 49.2 | 43.9 | 45.9 | 46.3 | 91.6 | 91.7 | 93.0 | 92.1 | 3,244 | 3,235 | 3,258 | 3,245 |
| 5.0% | | 50.8 | 43.6 | 45.0 | 46.5 | 91.0 | 90.5 | 91.9 | 91.1 | 3,164 | 3,145 | 3,164 | 3,158 |
| 7.5% | | 46.7 | 40.0 | 41.9 | 42.9 | 89.6 | 89.1 | 90.8 | 89.8 | 3,088 | 3,080 | 3,070 | 3,079 |
| SEM[4] | | 1.43 | 0.93 | 0.80 | 0.66 | 0.21 | 0.20 | 0.35 | 0.17 | 9.2 | 8.3 | 8.5 | 5.2 |
| Effect | | Probability | | | | | | | | | | | |
| Age[5] | 2 | | | | L***, Q*** | | | | L***, Q*** | | | | Q** |
| Diet | 6 | | | | *** | | | | *** | *** | *** | *** | *** |
| C1 = Control vs. fiber | 1 | | | | *** | | | | NS | *** | ** | ** | |
| C2 = Source | 1 | | | | * | | | | *** | * | * | *** | |
| C3 = Level[6] | 2 | | | | L***, Q* | | | | L*** | L*** | L*** | L*** | |
| C4 = Source × level | 2 | | | | * | | | | NS | * | NS | NS | |
| C4.1 = OH[7] | | | | | NS | | | | - | L*** | - | - | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| C4.2 = SBP[8] | | L***, Q* | - | L*** | - | - | |
| Diet × age | 12 | NS | NS | | | | ** |

[1]$n = 42$.

[2]$n = 6$ for the mean within each day and $n = 18$ for the average value at 6, 12, and 18 d.

[3]$n = 18$ for the mean within each day and $n = 54$ for the average value at 6, 12, and 18 d.

[4]$n = 12$ for the mean within each day and $n = 36$ for the average value at 6, 12, and 18 d.

[5]Linear (L) and quadratic (Q) contrasts for age effect.

[6]Linear (L) and quadratic (Q) contrasts for level of fiber effect (2.5, 5, and 7.5%).

[7]Linear (L) contrast for the OH diets.

[8]Linear (L) and quadratic (Q) contrasts for the SBP diets.

*$P < 0.05$; ** $P < 0.01$; *** $P < 0.001$.

**Table 14.** Effect of source [oat hulls (OH) and sugar beet pulp (SBP)] and level of inclusion (Level) of fiber of the diet on the apparent ileal digestibility of the nutrients (%) in broilers at 18 d of age

| *Item* | df | DM | Organic matter | Nitrogen |
|---|---|---|---|---|
| Diet | | | | |
| Control, 0% | | 71.4 | 75.0 | 74.9 |
| OH, 2.5% | | 73.4 | 77.3 | 76.1 |
| OH, 5.0% | | 73.1 | 76.6 | 76.6 |
| OH, 7.5% | | 68.9 | 72.5 | 78.9 |
| SBP, 2.5% | | 69.3 | 72.9 | 77.5 |
| SBP, 5.0% | | 66.9 | 70.7 | 76.4 |
| SBP, 7.5% | | 67.5 | 70.9 | 76.2 |
| SEM[1] | | 1.26 | 1.27 | 1.13 |
| Source of fiber | | | | |
| OH | | 71.8 | 75.5 | 77.2 |
| SBP | | 67.9 | 71.5 | 76.6 |
| SEM[2] | | 0.72 | 0.73 | 0.65 |
| Level of fiber | | | | |
| 2.5% | | 71.3 | 75.1 | 76.8 |
| 5.0% | | 70.0 | 73.6 | 76.5 |
| 7.5% | | 68.2 | 71.7 | 77.5 |
| SEM[3] | | 0.89 | 0.90 | 0.80 |
| Effect | | | Probability | |
| Diet | 6 | ** | ** | NS |
| C1 = Control vs. fiber | 1 | NS | NS | NS |
| C2 = Source | 1 | *** | *** | NS |
| C3 = Level[4] | 2 | L* | L* | NS |
| C4 = Source × level | 2 | NS | NS | 0.078 |
| C4.1 = OH[5] | | - | - | $L^{0.087}$ |
| C4.2 = SBP | | - | - | NS |

[1]$n$ = 6.

[2]$n$ = 18.

[3]$n$ = 12.

[4]Linear (L) contrast for the level of fiber effect (2.5, 5, and 7.5%).

[5]Linear (L) contrast for the OH diets.

*$P < 0.05$; ** $P < 0.01$; *** $P < 0.001$.